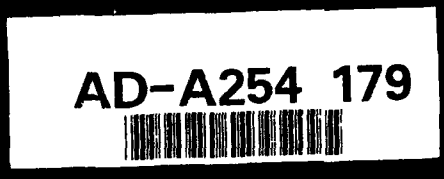
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A compact, quasi-active delay-line limiter/filter (QUADLF) was designed to limit high-power, fast-rise-time pulses and prevent spike leakage, which is common to conventional limiting techniques. The QUADLF design incorporates both waveguide and microstrip technologies. Over the operating frequency range, from 0.8 to 1.2 GHz, experimental results showed less than 2-dB transmission loss below 10-mW input power and greater than 20-dB in-band isolation above 5.0-W input power.

Design procedures are outlined and experimental data are presented that demonstrate feasibility and applicability. Data on frequency response, temporal response, and isolation characteristics are also shown.

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1. Introduction

Conventional limiting techniques to protect against unwanted radio frequency (rf) signals in many cases leave the front end of an electronic system susceptible to HPM pulses because of spike leakage [1]. Spike leakage is the microwave energy that escapes through the limiter before it has time to turn on. For PIN diode limiters, the thickness of the intrinsic region (I-region) is proportional to this turn-on time [2]. Unfortunately, the I-region thickness is directly proportional to the amount of power the diode can safely absorb. Hence a compromise between I-region thickness and turn-on time is required, and as a result conventional high-power limiters tend to have spike leakage energies of about 100 nJ.

Spike leakage in limiting devices has become a considerable factor as more and more microwave systems incorporate semiconductor devices with small junctions as components in their front ends. Consequently, the amount of energy needed to damage components of certain systems has decreased. For a particular limiter the energy "leaking through" is determined by

$$E = \int_0^{\tau} P(t)\, dt \ . \tag{1}$$

Even if the turn-on time (τ) is relatively small, the power can be of sufficient magnitude to create enough energy to damage or upset military systems. For example, energies of about 1 μJ can damage modern monolithic microwave integrated circuit (MMIC) devices [3], and energies as small as 0.05 μJ (50 nJ) can damage high-electron mobility transistors (HEMTs) [4].

A hardening solution for the front end of many systems would be a device that filters all out-of-band rf and provides limiting in-band with no spike leakage. Since spike leakage is a direct result of the turn-on time of the limiter configuration to the incoming HPM signal, it can be eliminated if the limiter is turned before the pulse arrives. A mechanism must be provided to sense power levels above a given threshold and turn on the limiter before the HPM signal arrives. We could achieve this effect by inserting an element that delays the major portion of the input signal while a small portion of the signal is used to turn on the limiter. The result is that the limiter is completely turned on when the HPM signal arrives—thus no spike leakage. Figure 1 is an idealized frequency response for the quasi-active delay-line limiter/filter (QUADLF).

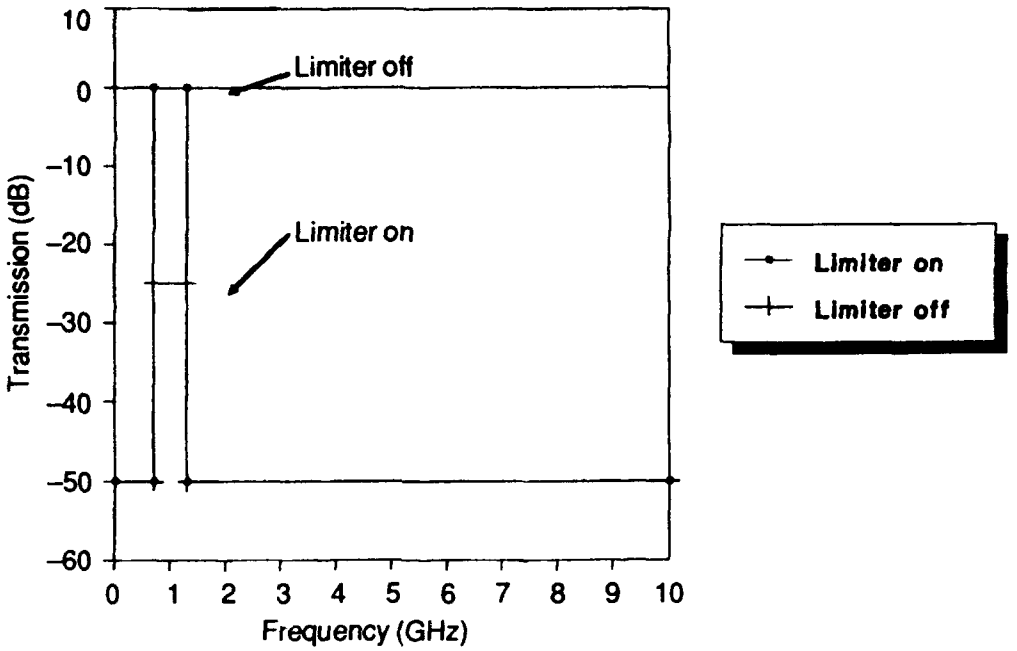


Figure 1. Idealized frequency response for QUADLF.

2. Design

Figure 2 is a block diagram of the QUADLF and figure 3 is a schematic diagram of the entire device. The device is made up of five separate components: a waveguide delay line/filter, a microstrip coupler, a two-diode detector, along with a biasing arm, and finally a dual PIN diode limiter.

2.1 Waveguide Delay Line/Filter

2.1.1 *Waveguide Delay Line*

To fabricate the delay line, rectangular blocks of high-dielectric ceramic material were obtained. This material has a relative dielectric constant (ε_r) of 80 and a loss tangent ($\tan\delta$) of about 1.8×10^{-4} at 1 GHz. Figure 4 shows plots of manufacturer specifications for Q and ε_r. We were able to obtain blocks with length (L) of 15.24 cm, width (a) of 2.57 cm, and height (b) of 1.4 cm.

We created a waveguide by coating the ceramic blocks with a layer of copper. With the given geometry we calculated the cutoff frequency (f_c) and the phase velocity in the TE_{10} mode ($m = 1$, $n = 0$) as

$$f_c = \left(c\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}/2\sqrt{\mu_r\varepsilon_r}\right) = (v/2a) = 0.6514 \text{ GHz} ,$$

where

Figure 2. Block diagram of QUADLF.

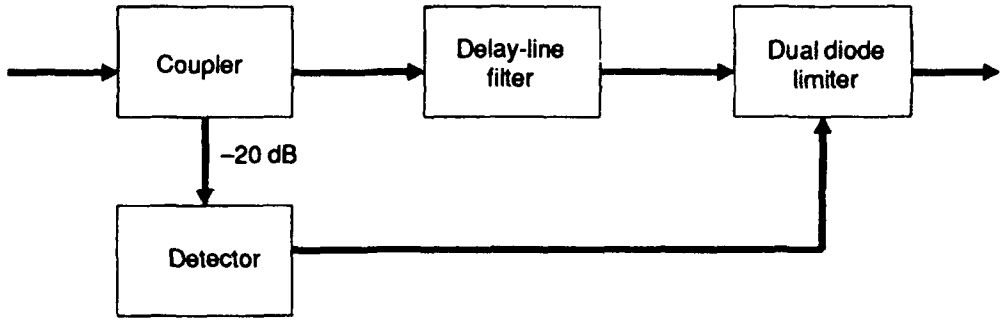
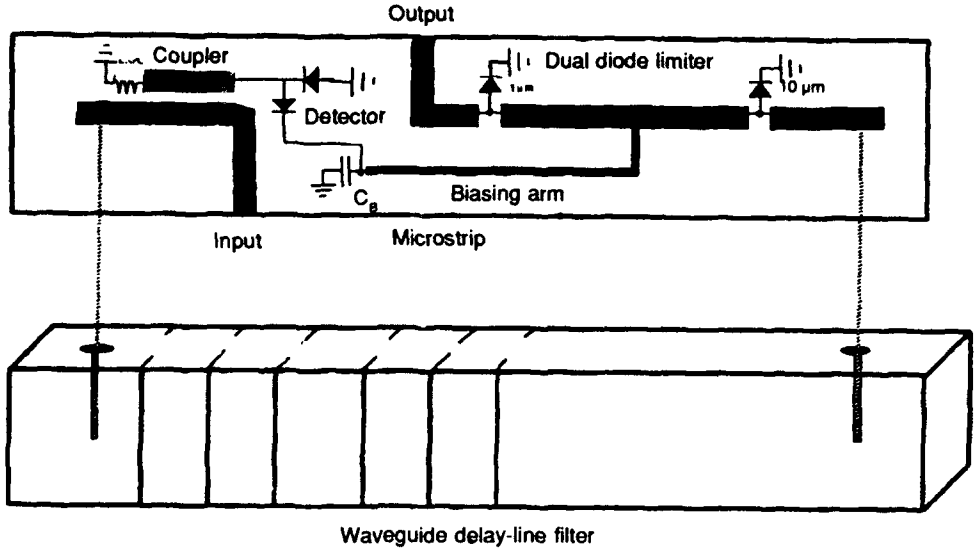


Figure 3. Schematic diagram of prototype device.



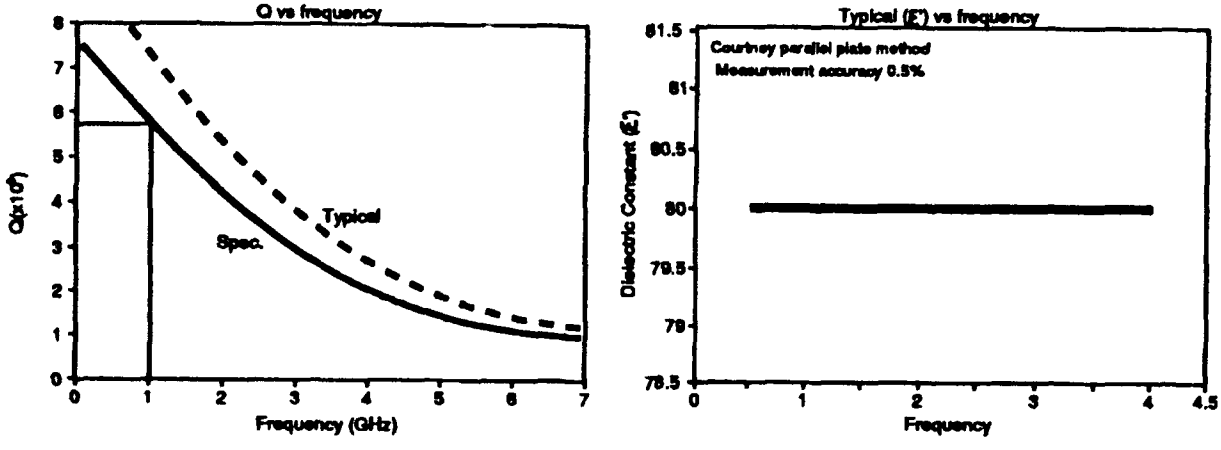


Figure 4. Plots of Q and ε_r versus frequency.

c = the speed of light in free space = 3.0×10^{10} cm/s,

μ_r = the relative permeability of the material = 1.0, and

$$v = \frac{c}{\sqrt{\varepsilon_r}} .$$

Also

$$v_{ph} = (v)/\left(\sqrt{1-\left(\frac{f_c}{f_0}\right)^2}\right) = 4.45 \times 10^9 \text{ cm/s} ,$$

where

f_0 is the operating frequency, 1 GHz.

Spaces for probes were drilled out at $\lambda_0/4$ deep and a distance of $\lambda_g/4$ away from the waveguide ends (see fig. 5). The wavelength in the material (λ_0) is calculated as

$$\lambda_0 = \frac{v}{f_0} = 3.38 \text{ cm} .$$

The guide wavelength (λ_g) is

$$\lambda_g = \frac{v_{ph}}{f_0} = 4.45 \text{ cm} .$$

The group velocity is

$$v_{gr} = \left(c\sqrt{1-[(f_c^2/f_0)]}/(\sqrt{\varepsilon_r \mu_r})\right) = v\sqrt{1-[(f_c^2/f_0)]} = 2.56 \times 10^9 \text{ cm/s} .$$

The delay provided by the waveguide delay line is

$$\tau_D = (L/v_{gr}) = 5.95 \text{ ns} ,$$

where

L = the waveguide length = 6 in.

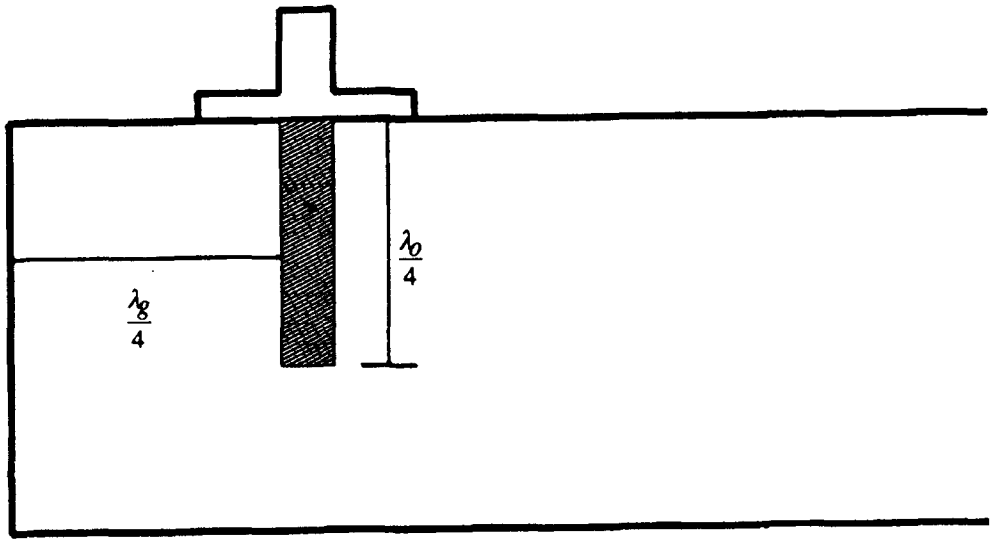


Figure 5. Waveguide diagram showing placement of launchers.

This result agreed with the actual measurement of the delay, which was ~6 ns (see fig. 6).

2.1.2 *Waveguide Cavity Filter*

An excellent filter structure was designed inside the waveguide itself: a five-element waveguide cavity filter. Figure 7 indicates the positioning of the metal inserts that divide the elements, thereby creating separate cavities within the waveguide. The spacing and penetration of the inserts determine the filter response. Not only did the structure provide an adequate filtering response, but also it provided an additional delay to the delay line. Figure 8 is the measured frequency response (S_{21}) of the device. Figure 8(a) shows the response for the

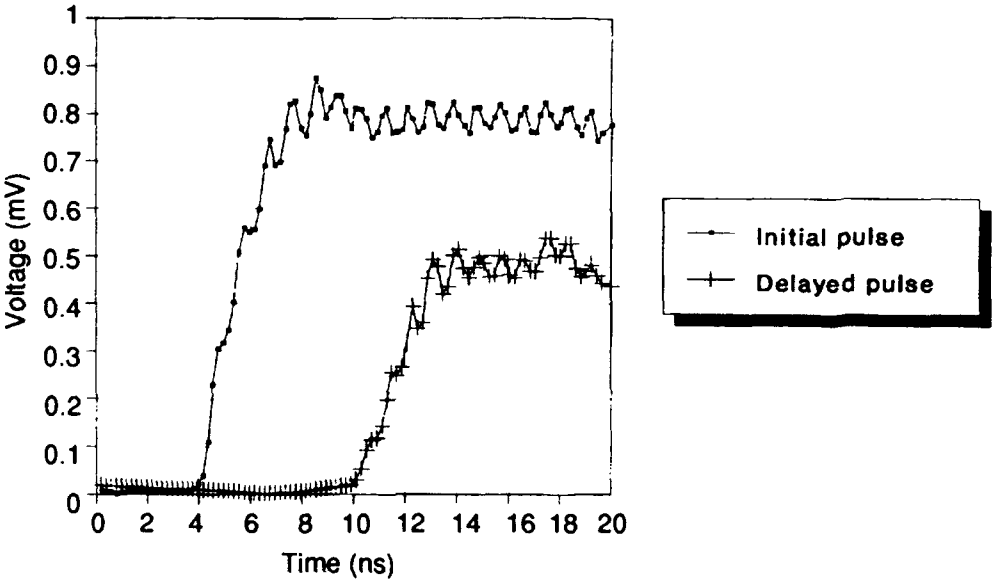


Figure 6. Port-to-port delay for waveguide delay line.

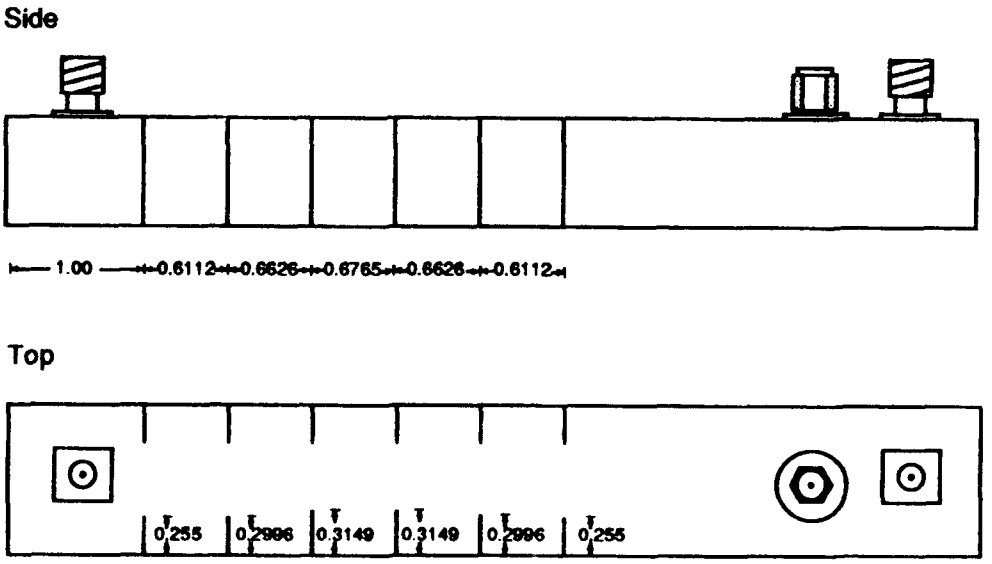


Figure 7. Waveguide cavity filter schematic.

entire frequency range from 0.2 to 10 GHz. A good window is formed in the passband from about 0.8 to 1.2 GHz. Below the passband, the inherent cutoff properties of the waveguide act as an ideal filter. Above band are some fairly high peaks that could be pushed farther down into the noise by better manufacturing techniques. Figure 8(b) is a closer look at the passband. Although there is an exceptionally

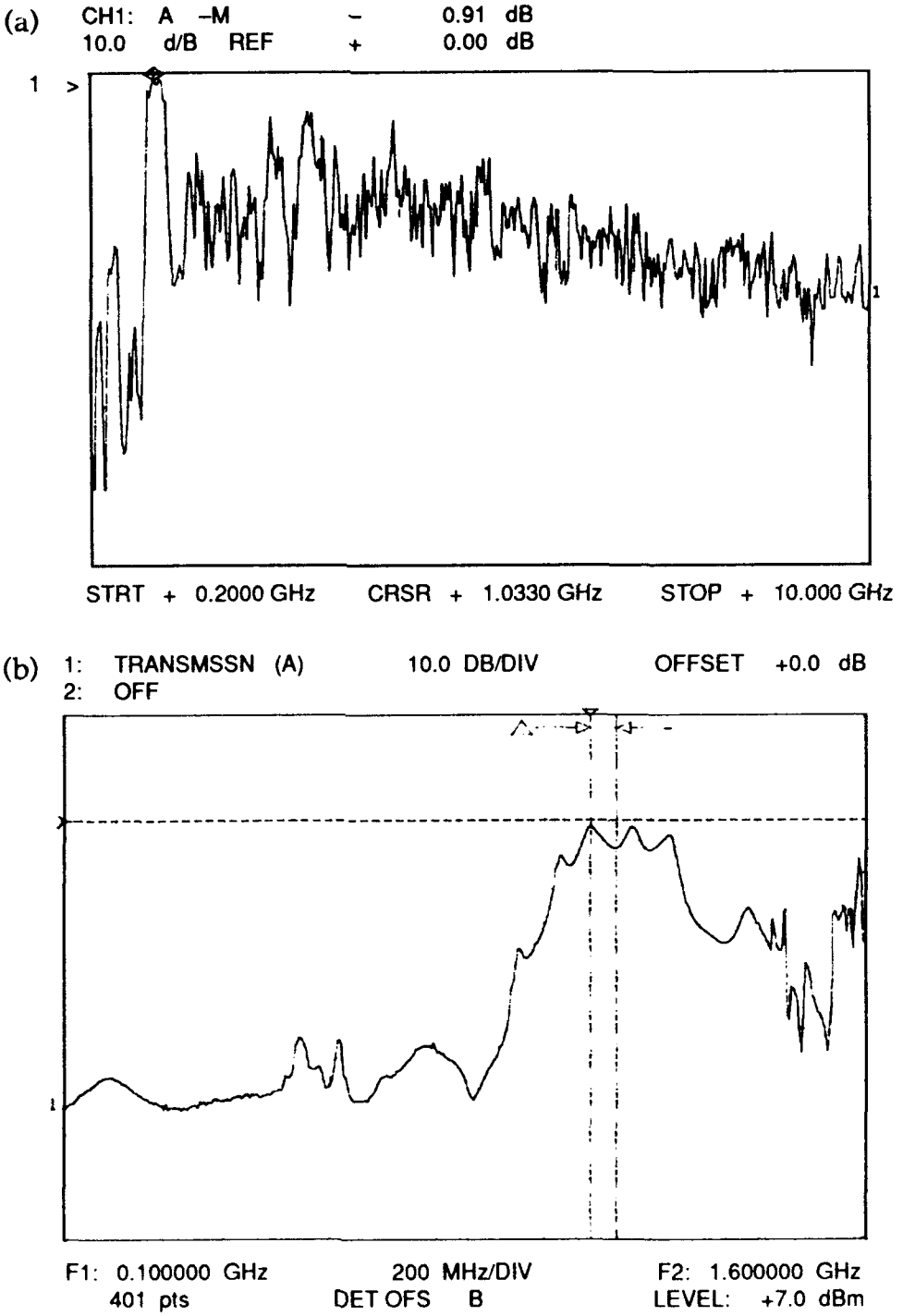


Figure 8. Measured frequency response (S_{21}) of delay-line filter: (a) response for expanded frequency range and (b) passband .

good cutoff below band, and a well-defined passband window, the ripple within it is fairly intense. Again, more precise manufacturing (specifically the filter) would improve the response considerably. The delay was measured as well, and was shown to be 12.4 ns (see fig. 9). The filter was designed using the equations provided by Matthaei, Young, and Jones [5]. These equations were implemented using a computer program, FILTER, written by the author. The Pascal source code, FILTER.PAS, is in appendix A.

2.2 20-dB Microstrip Coupler

A microstrip coupler is used to tap off a portion of the incident power for biasing the limiter diodes. It is a simple coupled line configuration (see fig. 3). A combination of spacing and line width determines the amount of coupling provided. The circuit was modelled on TOUCHSTONE (see app B). Figure 10 is the output from the model.

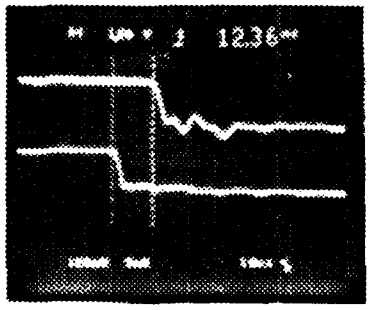


Figure 9. Measured delay of delay-line filter.

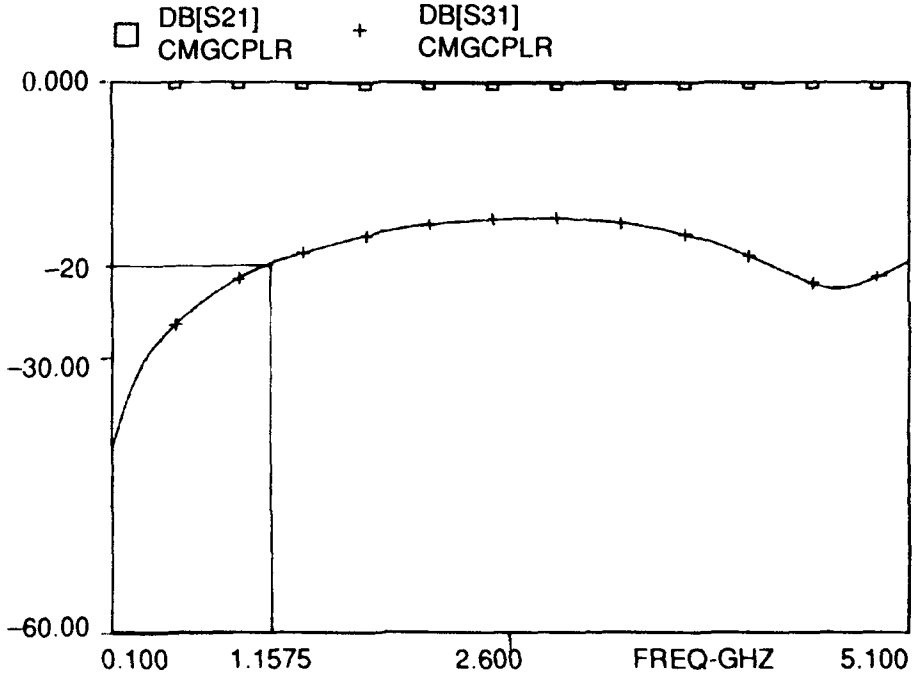


Figure 10. Touchstone output for microstrip coupler.

It is also important to note that the coupler acts as a line of protection for the detector diodes; 20 dB was initially chosen as the coupling value.

2.3 Two-Diode Detector Circuit

We chose the term "quasi-active" because of our method of using a rectified portion of the incoming signal to bias the limiter diodes positively. To do this, we designed a half-wave rectifier circuit (see fig. 3) using two Texas Instruments detector diodes, type A-1149. In earlier experimentation these were found to have the fastest turn-on time of all the detector diodes available to us.

The I-V curve for the two-diode limiter circuit (fig. 11) shows that V_γ is approximately equal to 670 mV, where V_γ is the minimum turn-on voltage of the limiter diode configuration. According to the calibration curve for the detector (fig. 12), it takes a power level of 1.4 W to produce this voltage.

With the detector circuit feeding off a 20-dB coupler, power of 140 W would be needed to achieve complete limiter turn-on. We can reduce this needed power level either by producing a more efficient detector circuit or decreasing the coupling value. The detector circuit configuration we began with was found to be the most efficient. Therefore, the coupling value was reduced experimentally.

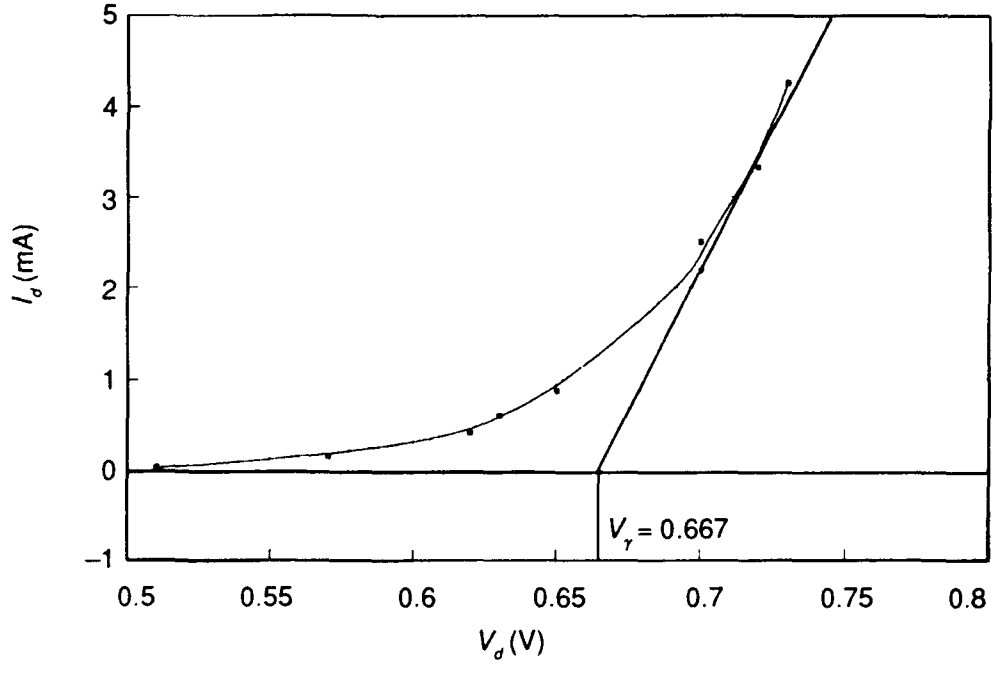
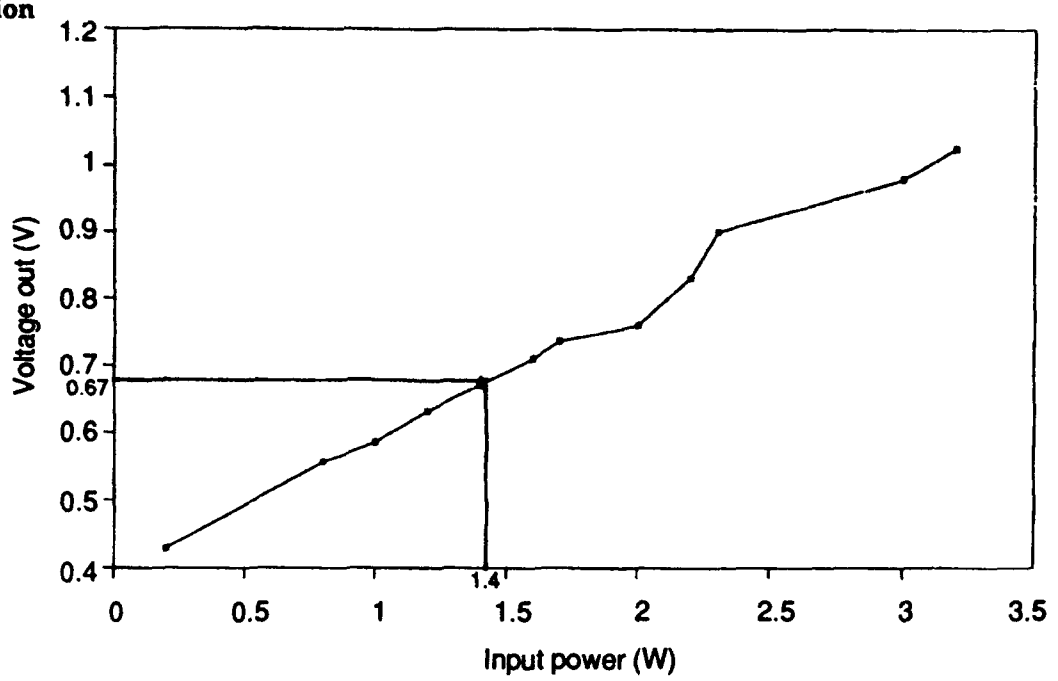


Figure 11. I-V characteristics for dual-diode limiter.

Figure 12. Calibration curve for detector circuit.



2.4 Biasing Arm

Biasing is done by connecting the output of the rectifier to the center of the line containing the limiter diodes (see fig. 3). In order to properly bias the limiter diodes without interfering with the desired circuit response, we needed a DC biasing arm that was invisible to rf. To do this we connected the detector diodes and a high impedance, quarter-wavelength (at 1 GHz) biasing arm to ground through a capacitor (C_B). If C_B is properly valued, then rf will see a quarter-wavelength shorted stub while DC will see a pathway through the limiter diodes. Two conditions had to be met: First, the impedance of the biasing arm had to be much greater than the impedance of the line containing the limiter diodes; that is

$$Z_a >> Z_0 \ ,$$

which we did by making the biasing line with very thin wire. Secondly, we wanted the impedance of the capacitor to be very small at the operating frequency, where

$$|Z_{CB}| \sim 1\ \Omega$$

at 1 GHz.

Then

$$C_B = (1/2\ \pi f_0) = 159\ pF \ .$$

Of course at DC, Z_{CB} is nearly infinite.

2.5 Dual-Diode Limiter

We were able to incorporate into our model a dual-diode limiter design that was originally produced by Robert J. Tan of Harry Diamond Laboratories [1]. According to Tan, the maximum energy level of spike leakage allowed, with all tested configurations, was 100 nJ. Depending on the width of the intrinsic region of the thickest diode, we can determine the maximum power dissipation of the limiter. We opted to use 10- and 1-μm diodes configured such that the larger diode is first to encounter the rf energy (fig. 13). With this configuration, we expected to see about 30 dB of isolation in-band. As can be seen from figure 3, a rectified portion of the input signal is used to bias the diodes. Considering the voltage response of the limiter (fig. 14) measured as a separate device, we see that the output voltage begins to level at about 0.7 V. The calibration curve made on the detector diode (fig. 12) shows that it takes about 1.4 W minimum input to the detector to achieve complete turn-on of the limiter. With the 20-dB coupler in place, 140 W of input power is needed to completely forward bias the limiter.

3. Experimental Results

Figure 15 shows the laboratory setup diagram that was used in this experiment. This configuration was such that both input and output power could be determined. By the time of experimentation, the coupler value was adjusted to 10 dB. This reduced the 140-W input power requirement to 14 W for completely forward-biasing the limiter diodes. Spike leakage still existed at the low power levels. We took measurements of input power and output power in the flat and spike

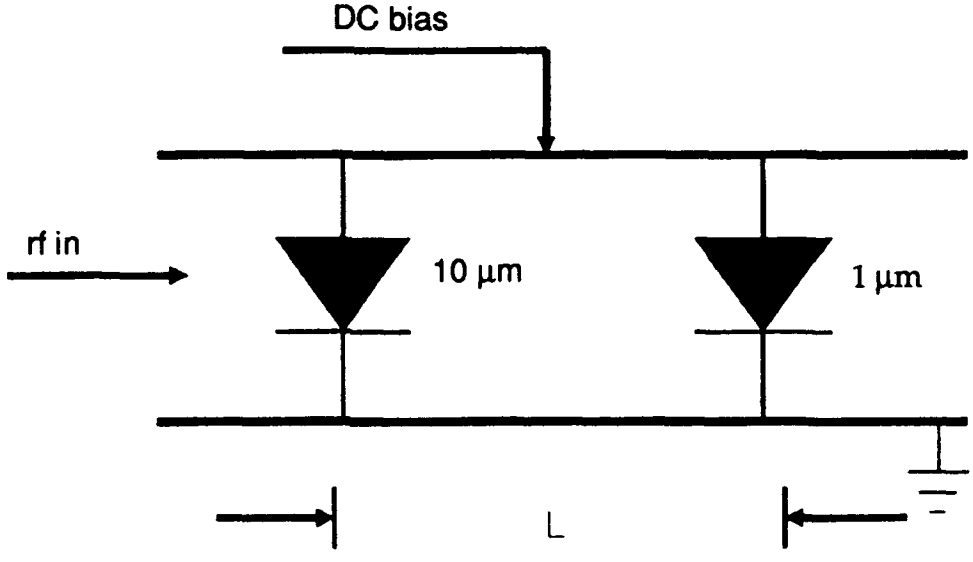


Figure 13. Dual-diode limiter schematic.

regions. Our input pulses had risetimes of about 5 ns. Figure 16 shows a plot of these data, along with isolation lines. Due to limitations with our power sources, we were unable to acquire data above 11 W. Figure

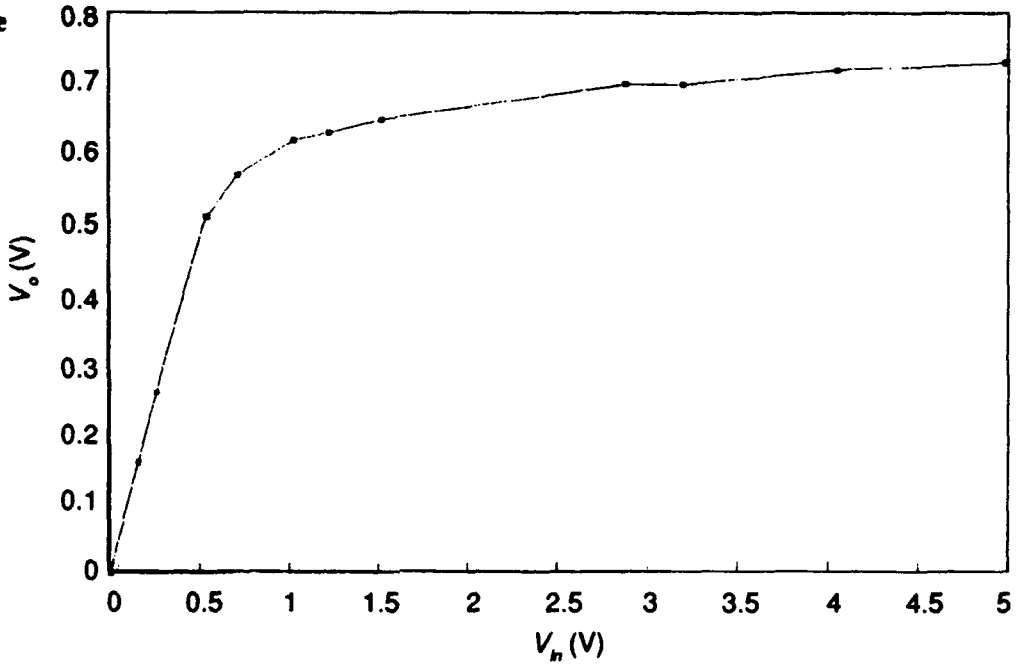


Figure 14. Dual-diode limiter voltage response.

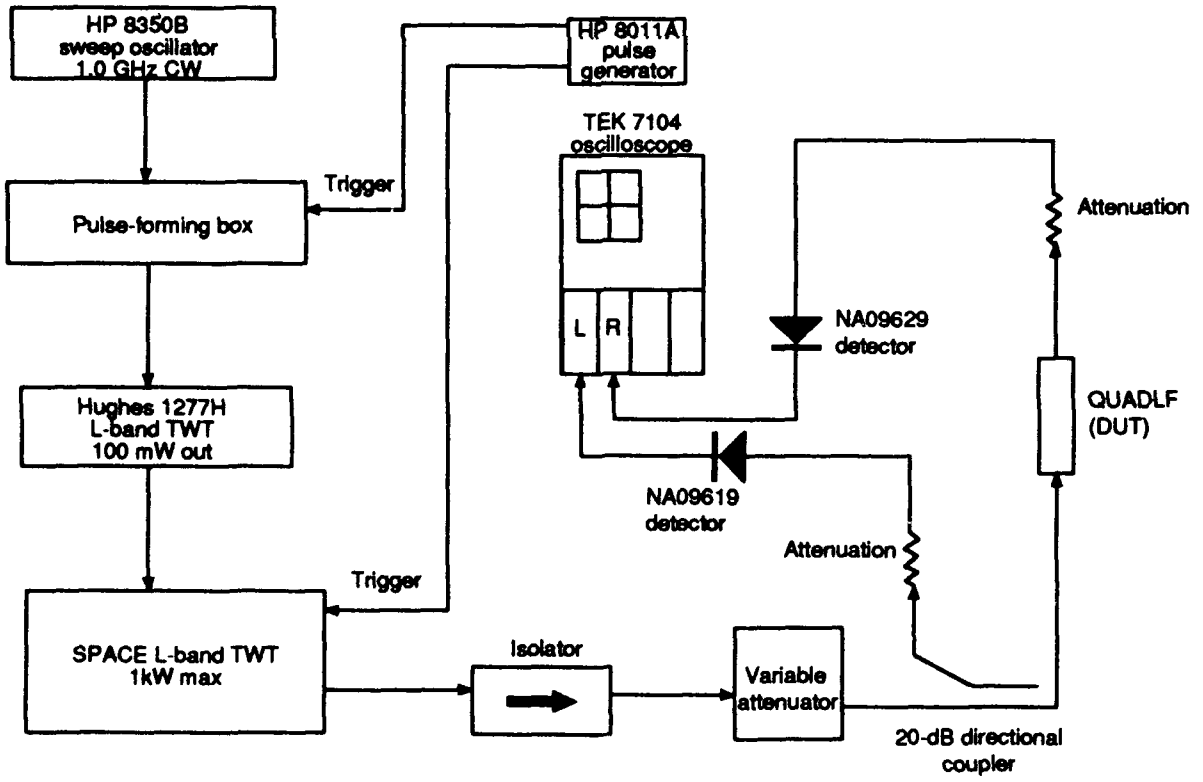


Figure 15. Laboratory setup diagram.

16 also shows that above 5 W the device gives about 20 dB of isolation, and above 10 W spike leakage disappears. This confirms the fact that the limiter diodes are beginning to completely turn on before the signal arrives at the diodes. At 10 W, the detector is putting out nearly 0.6 V. Figure 17 is a plot of spike energy out versus power in. Here we see a maximum energy of about 3.3 nJ at 0.3-W input. Above 10 W we see an energy of 0.6 nJ. This energy includes the energy in the spike as well as the flat leakage energy (see fig. 18).

The limiter configuration chosen was for the robustness of the 10-μm (I-region thickness) diode and the speed of the 1 μm. The experiment indicated that a single diode (either 10 or 1 μm) had much higher spike-leakage energies than the QUADLF using the dual diode limiter

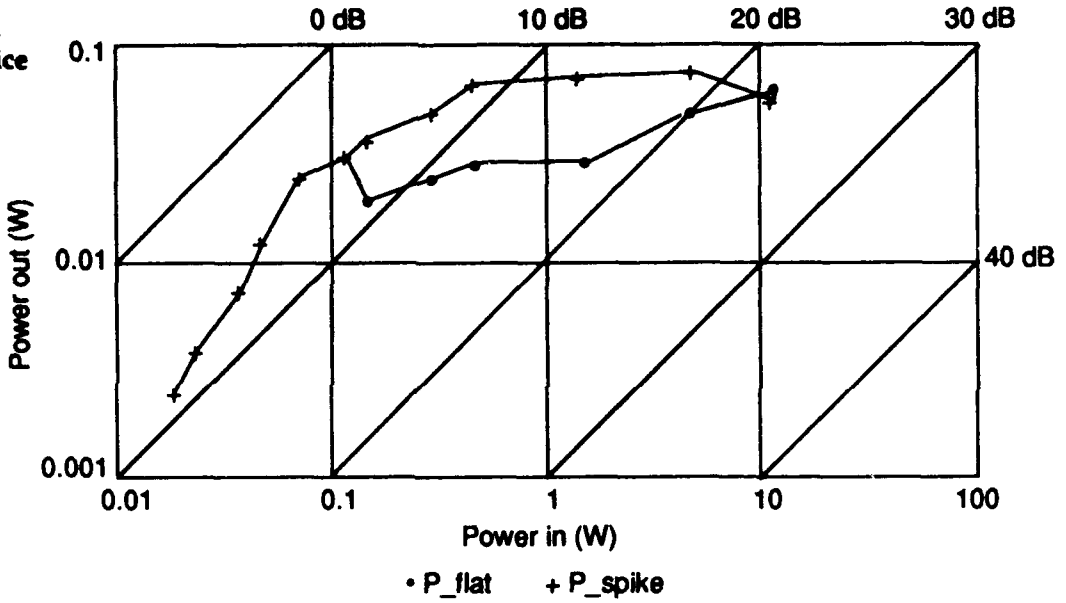


Figure 16. Isolation techniques for device with 10- and 1-μm dual-diode limiter.

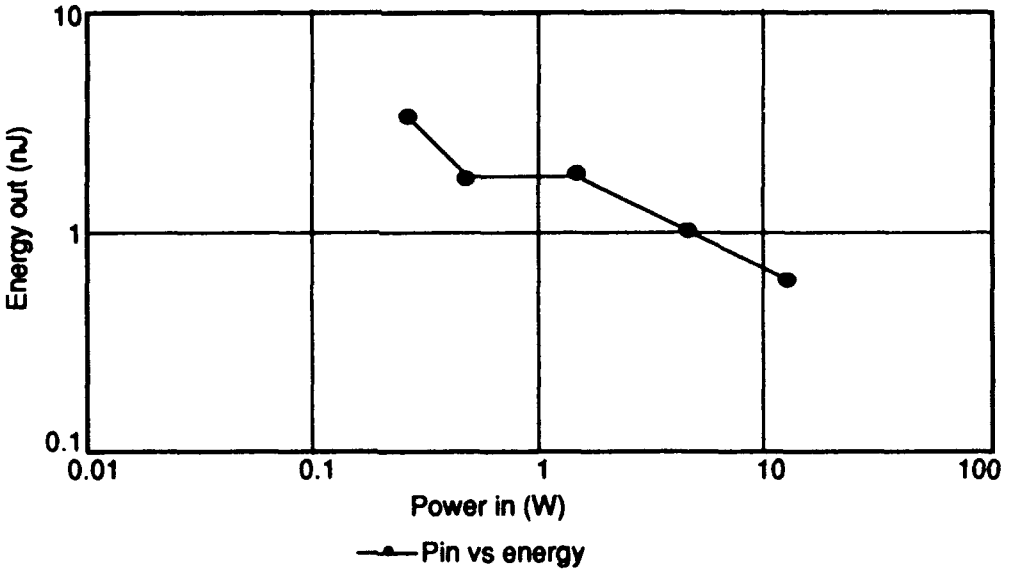


Figure 17. Spike energy out versus input power.

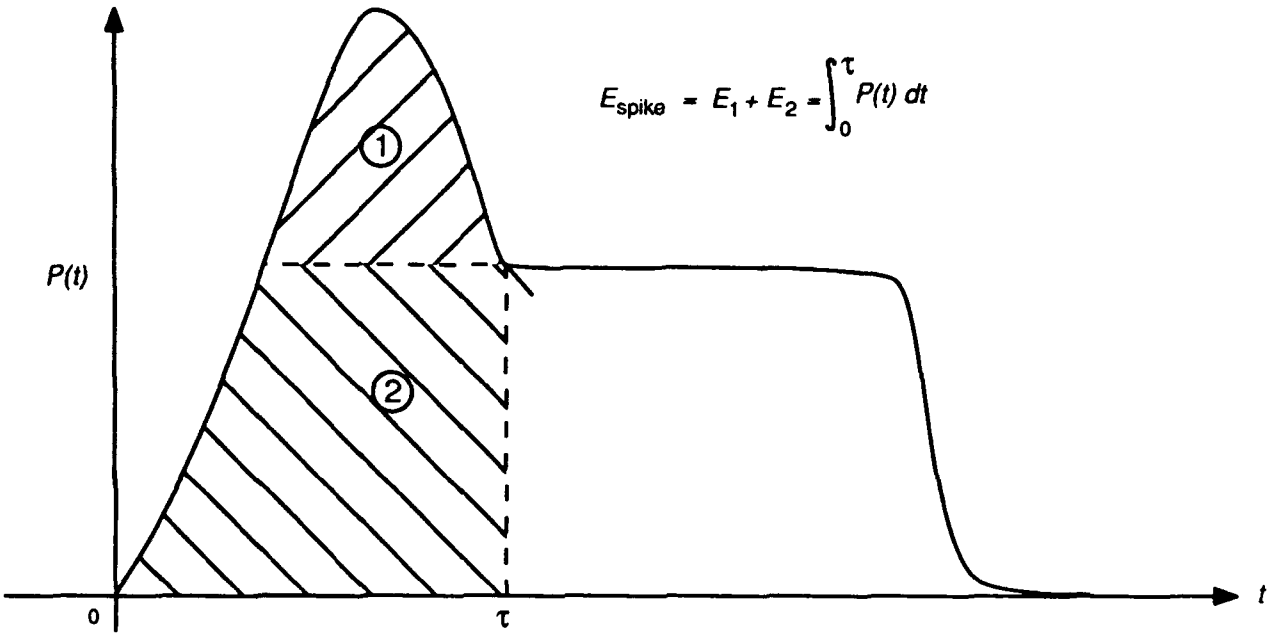


Figure 18. Calibration of spike energy.

configuration. Also Tan's spike-energy curves tended to increase with input power (fig. 9). We can conclude from this that the delay has a positive effect in influencing spike leakage.

4. Conclusions

Individually, each component of the QUADLF works within specified parameters. Cascading these elements introduces mismatches that tend to degrade the overall performance. Probably the most obvious example is the transition from the waveguide launchers to the microstrip circuit board. There are reflections caused by both machining discontinuities and impedance mismatch. The output frequency response of the device shown in figure 8 is representative of these effects. Better machining and more sophisticated matching attempts may improve the matching significantly enough to reduce the insertion loss to below 1 dB. As stated earlier, the delay has an influence on the total spike energy leaking through. The QUADLF reduces spike leakage and even eliminates it above 10-W input power.

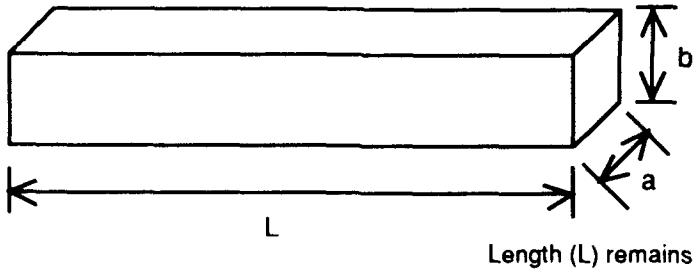
Pulse width of the input pulse is a factor in the performance of the QUADLF. If a very narrow pulse, say less than 12 ns, enters the device, the limiter diodes will be biased on and off *before* the pulse reaches them because of the <12-ns delay given by the delay line. However, if this pulse is of any significant power, the diodes will limit on their own. A 12-ns pulse (or less) must be of a very significant power level to cause any type of damage or upset to a system.

Because waveguide is being used as the delay line and the filter, its size decreases as frequency increases. Figure 19 shows an approximate size/weight consideration of the entire device for different frequency bands of interest. Also, the microstrip line lengths decrease as the frequency increases. This would make the QUADLF more compact as frequency of operation is increased.

Finally, this work demonstrates that it is possible to design a device that limits high-power, fast-rise-time pulses and significantly reduces spike leakage, even eliminating it above a certain threshold. Size and weight are critical considerations in today's systems. With this in mind, we see that a material with an even higher relative dielectric constant ($\varepsilon_r = 100$) would reduce the length of the QUADLF and thus the weight as well. If the manufacturing is done with care, many losses and mismatches can be reduced.

5. Future Work

Several things can be done to improve upon and add to this work. First of all, a much better device could be machined using the design criteria laid out in this report. More attention should be given to mismatches between device elements. Design objectives should be a much cleaner passband with minimal loss, and an out-of-band response that is nearer to the noise floor. The in-band isolation of the limiter could be improved to 30 dB or better for the input power levels tested. Secondly, more of the parameters should be varied for future tests. Higher input power levels, faster and slower risetimes, different frequencies, and even variations on the modulation scheme—all could be used to completely characterize the device. Thirdly, several different diode pairs should be used in the limiter configuration to



Length (L) remains constant

Figure 19. Approximate size/weight variation with frequency band.

Frequency band	Volume (cubic in.)	Weight (lb)
L	3.0	0.8
S	0.8	0.2
C	0.2	0.1
X	0.1	0.1

determine the limits between robustness and speed, so that a system designer can make the best choice according to the application. Finally, the problem of matching into a variable load impedance can be studied. This problem arises when we try to transfer maximum voltage from the detector diodes into the limiter diodes. In this case both the source and load impedances are changing. Normally, one impedance value is picked and matching is done for that case. It would be much better to match over the entire impedance dynamic range.

Acknowledgements

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Thanks to Robert Tan for insight and ideas.

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[3] Jeffrey E. Casper, ed., SRI International, *High-Power-Microwave Hardening Design Guide for Systems*, Harry Diamond Laboratories, HDL-CR-89-709-2b, contract DAAL01-87-C-0709 (15 October 1989).

[4] J. McAdoo, Briefing on MMIC Damage, Harry Diamond Laboratories Program Review, Mission Research Corp., Newington, VA (18 April 1990).

[5] G. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks*, and Coupling Structures, McGraw-Hill, New York (1964).

Appendix A. FILTER Program Source Code

```
Program FILTER;
Uses CRT,PRINTER;

{ Program name: FILTER.PAS:

    Purpose:      Implements design specifications for the design
                  of low-pass and bandpass filters. Returns lumped
                  element values as well as impedance and line length
                  information for transmission-line applications. Also
                  calculates parameters for waveguide filter structures.

    References:   G. Matthaei, L. Young, and E. M. T. Jones, Microwave
                  Filters, Impedance-Matching Networks, and Coupling
                  Structures, McGraw Hill, Inc., New York (1964), ch 4 and 8;
                  new edition, Artech (1982).

                  Edward Wolff and Roger Kaul, Microwave Engineering
                  and Systems Applications, John Wiley and Sons (1989), Ch 9.

    Programmer:   Chance M. Glenn, Harry Diamond Laboratories,
                  in conjunction with Quasi-Active Delay Line/Filter
                  project.

                  Date of latest modification: 07-25-90          }

Var
    Elem,g,Z,GT,Ce,CMe,Cfe,Jkk,Cs,spacing,
    width,KZ0,XZ0,Theta,XZ0La,da,d: ARRAY[0..50] of REAL;
    a,b,t,f0,f1,f2,ripple,Z0,Y0,omega1,epsilon,Zs,omegaQ,Lambda4,Yaj,
    omega2,theta0,w,bj,YA,omega0,tbratio,L,ICfe,lambda0,wL: REAL;
    nelements,i,j,k,initelement: INTEGER;
    ID,DATE: STRING;
    Units: ARRAY[0..50] of STRING;
    Choice: INTEGER;
    dFLAG: BOOLEAN;
Const
    pi = 3.1415926547;
    c = 1.18102362E+10;        {Speed of light in in/s}
    omega1prime = 1.0;
```

Appendix A

```
Function TAN(phi: REAL): REAL;
Begin
      Tan := Sin(phi)/Cos(phi);
End;

Function COT(phi: REAL): REAL;
Begin
      Cot := 1.0/Tan(phi);
End;

Function CSC(phi: REAL): REAL;
Begin
      Csc := 1.0/Sin(phi);
End;

Function SINH(phi: REAL): REAL;
Begin
      Sinh := (Exp(phi)-Exp(-phi))/2.0;
End;

Function COTH(phi: REAL): REAL;
Begin
      Coth := Exp(-phi)/(Exp(phi)-Exp(-phi))*2+1;
End;

Function Lambdag(f,e,a: REAL): REAL;
Begin
      Lambdag := c/(f*SQRT(e*(1.0-SQR(c/(2.0*a*SQRT(e)*f)))));
End;

Procedure MAKE_WINDOW(x0,y0,width,wlength,bordercolor,windowcolor,
shadowcolor,titlecolor: INTEGER; Title: STRING);
var
      j,center,ptitle: INTEGER;
Begin
      ptitle := (Width div 2)-(Length(title) div 2);
      Window(x0+2,y0+1,x0+width+2,y0+wlength+1);
      Textbackground(shadowcolor);
      Clrscr;
      Window(x0,y0,x0+width,y0+wlength);
      Textbackground(windowcolor);
      Clrscr;
```

```
        Textcolor(bordercolor);

        GotoXY(1,1);
        Write(#218);
        GotoXY(1,wlength+1);
        Write(#192);
        For j := 2 to wlength do
        Begin
                GotoXY(1,j);
                Write(#179);
                GotoXY(width,j);
                Write(#179);
        End;

        GotoXY(width,1);
        Write(#191);
        GotoXY(width,wlength+1);
        Write(#217);
        For j := 2 to width-1 do
        Begin
                GotoXY(j,1);
                Write(#196);
                GotoXY(j,wlength+1);
                Write(#196);
        End;
        Textcolor(titlecolor);
        GotoXY(ptitle,1);
        Write(' ',title,' ');

End;

Procedure HOLDUNTIL(Check: CHAR);
var
        Letter: CHAR;
Begin
          Letter := #0;
          While (Letter <> Check) do
          Begin
              Letter := Readkey;
          End;
          Letter := #0;
End;
```

```
Procedure INTRO;
Begin
        Textbackground(15);
        Clrscr;
        MAKE_WINDOW(10,3,60,18,14,1,8,15,'FILTER CALC');
        Textcolor(12);
        GotoXY(15,3);
        Write('Filter Synthesis Calculations');
        GotoXY(15,4);
        Write('------------------------------');

        Textcolor(10);
        GotoXY(8,6);
        Write('  An interactive program which performs calcu-');
        GotoXY(8,7);
        Write('lations for various microwave filter structures.');
        GotoXY(14,14);
        Write('Programmer:    Chance M. Glenn');
        GotoXY(17,15);
        Write('Harry Diamond Laboratories');
        Textcolor(31);
        GotoXY(23,19);
        Write(' Press Esc... ');
        HOLDUNTIL(#27);
        Textcolor(15);
        GotoXY(23,19);
        Write(' Press Esc... ');

End;


Procedure MENU1;
var
   ChNum: CHAR;
   errorcode: INTEGER;
Begin
        MAKE_WINDOW(12,5,50,13,14,4,8,15,'Filter Types');
        Textcolor(3);
        GotoXY(12,6);
        Write('1. Quarter-wavelength Low-pass');
        GotoXY(12,7);
        Write('2. Inter-digital');
        GotoXY(12,8);
```

```
        Write('3. Comb-Line');
        GotoXY(12,9);
        Write('4. Waveguide');
        Textcolor(14);
        GotoXY(12,6);
        Write('1.');
        GotoXY(12,7);
        Write('2.');
        GotoXY(12,8);
        Write('3.');
        GotoXY(12,9);
        Write('4.');
        Textcolor(31);
        GotoXY(16,14);
        Write(' Select number... ');

        ChNum := #32;
        While (ChNum<>'1') and (ChNum<>'2') and (ChNum<>'3') and
        (ChNum<>'4') do
        Begin
        ChNum := Readkey;
        End;
        Val(ChNum,Choice,errorcode);

        Textcolor(15);
        GotoXY(16,14);
        Write(' Select number... ');
End;


Procedure LOW_PASS_INPUT;
var
        MChoice: CHAR;
        errorcode: INTEGER;
Begin

        MAKE_WINDOW(10,2,60,7,14,4,0,15,'Identification Information');
        GotoXY(3,3);
        Textcolor(2);
        Write('Project ID: ');
        Textcolor(10);
        Window(24,4,65,5);
        Readln(ID);
```

```
Window(10,2,70,9);
GotoXY(3,5);
Textcolor(2);
Write('Date: ');
Textcolor(10);
Window(19,6,50,7);
Readln(DATE);

MAKE_WINDOW(15,6,50,4,14,4,0,15,'Matching Information');
GotoXY(3,3);
Textcolor(2);
Write('System impedance (Ohms): ');
Textcolor(10);
Window(43,8,55,9);
Readln(Zs);

MAKE_WINDOW(15,10,50,6,14,4,0,15,'Physical Parameters');
GotoXY(3,3);
Textcolor(2);
Write('Relative dielectric constant: ');
Textcolor(10);
Window(47,12,57,11);
Readln(epsilon);
Window(15,9,65,15);
GotoXY(3,5);
Textcolor(2);
Write('Substrate thickness (inches): ');
Textcolor(10);
Window(47,13,55,14);
Readln(b);
Window(15,9,65,15);
GotoXY(3,6);
Textcolor(2);
Write('Conductor thickness (inches): ');
Textcolor(10);
Window(47,14,55,15);
Readln(t);

MAKE_WINDOW(15,13,50,6,14,4,0,15,'Frequency Information');
GotoXY(3,3);
Textcolor(2);
Write('Pass-band edge frequency (GHz): ');
Textcolor(10);
Window(49,15,57,16);
```

```
        Readln(f1);
        Window(15,13,65,18);
        GotoXY(3,5);
        Textcolor(2);
        Write('Cut off frequency (GHz): ');
        Textcolor(10);
        Window(42,17,55,18);
        Readln(f2);

        MAKE_WINDOW(15,16,50,6,14,4,0,15,'Modelling Specifications');
        GotoXY(3,3);
        Textcolor(2);
        Write('Ripple (dB): ');
        Textcolor(10);
        Window(30,18,57,19);
        Readln(Ripple);
        Window(15,16,65,22);
        GotoXY(3,4);
        Textcolor(2);
        Write('Number of elements: ');
        Textcolor(10);
        Window(37,19,55,21);
        Readln(nelements);
        Window(15,16,65,22);
        GotoXY(18,5);
        Textcolor(2);
        Write('Begin with...');
        GotoXY(5,6);
        Write('0. Shunt capacitor   1. Series inductor');
        Textcolor(10);
        GotoXY(5,6);
        Write('0.');
        GotoXY(26,6);
        Write('1.');

        MChoice := #0;
        While (MChoice <> '0') and (MChoice <> '1') do
        Begin
        MChoice := Readkey;
        End;
        Val(MChoice,initelement,errorcode);

End;
```

Appendix A

```
Procedure BAND_PASS_INPUT;
Begin

    MAKE_WINDOW(10,2,60,7,14,4,0,15,'Identification Information');
    GotoXY(3,3);
    Textcolor(2);
    Write('Project ID: ');
    Textcolor(10);
    Window(24,4,65,5);
    Readln(ID);
    Window(10,2,70,9);
    GotoXY(3,5);
    Textcolor(2);
    Write('Date: ');
    Textcolor(10);
    Window(19,6,50,7);
    Readln(DATE);

    MAKE_WINDOW(15,6,50,4,14,4,0,15,'Matching Information');
    GotoXY(3,3);
    Textcolor(2);
    Write('System impedance (Ohms): ');
    Textcolor(10);
    Window(43,8,55,9);
    Readln(Zs);

    MAKE_WINDOW(15,10,50,6,14,4,0,15,'Physical Parameters');
    GotoXY(3,3);
    Textcolor(2);
    Write('Relative dielectric constant: ');
    Textcolor(10);
    Window(47,12,57,11);
    Readln(epsilon);
    Window(15,9,65,15);
    GotoXY(3,5);
    Textcolor(2);
    Write('Substrate thickness (inches): ');
    Textcolor(10);
    Window(47,13,55,14);
    Readln(b);
    Window(15,9,65,15);
    GotoXY(3,6);
    Textcolor(2);
```

```
Write('Conductor thickness (inches): ');
Textcolor(10);
Window(47,14,55,15);
Readln(t);

MAKE_WINDOW(15,13,50,6,14,4,0,15,'Frequency Information');
GotoXY(3,3);
Textcolor(2);
Write('Lower edge frequency (GHz): ');
Textcolor(10);
Window(46,15,57,16);
Readln(f1);
Window(15,13,65,18);
GotoXY(3,5);
Textcolor(2);
Write('Upper edge frequency (GHz): ');
Textcolor(10);
Window(46,17,55,18);
Readln(f2);

MAKE_WINDOW(15,16,50,6,14,4,0,15,'Modelling Specifications');
GotoXY(3,3);
Textcolor(2);
Write('Ripple (dB): ');
Textcolor(10);
Window(30,18,57,19);
Readln(Ripple);
Window(15,16,65,22);
GotoXY(3,4);
Textcolor(2);
Write('Number of elements: ');
Textcolor(10);
Window(37,19,55,20);
Readln(nelements);
Window(15,16,65,22);
GotoXY(3,5);
Textcolor(2);
Write('Element electrical length (degrees): ');
Textcolor(10);
Window(55,20,62,21);
Readln(theta0);


End;
```

Appendix A

```
Procedure WAVEGUIDE_INPUT;
var
   instring: STRING;
   errorcode: INTEGER;
Begin
      dFLAG := FALSE;
      MAKE_WINDOW(10,2,60,7,14,4,0,15,'Identification Information');
      GotoXY(3,3);
      Textcolor(2);
      Write('Project ID: ');
      Textcolor(10);
      Window(24,4,65,5);
      Readln(ID);
      Window(10,2,70,9);
      GotoXY(3,5);
      Textcolor(2);
      Write('Date: ');
      Textcolor(10);
      Window(19,6,50,7);
      Readln(DATE);

      MAKE_WINDOW(15,6,50,4,14,4,0,15,'Matching Information');
      GotoXY(3,3);
      Textcolor(2);
      Write('System impedance (Ohms): ');
      Textcolor(10);
      Window(43,8,55,9);
      Readln(Instring);
      Val(Instring,Zs,errorcode);

      MAKE_WINDOW(15,10,50,6,14,4,0,15,'Physical Parameters');
      GotoXY(3,3);
      Textcolor(2);
      Write('Relative dielectric constant: ');
      Textcolor(10);
      Window(47,12,57,11);
      Readln(epsilon);
      Window(15,9,65,15);
      GotoXY(3,6);
      Textcolor(2);
      Write('Waveguide width (inches): ');
      Textcolor(10);
```

```
        Window(43,14,55,15);
        Readln(a);

        MAKE_WINDOW(15,13,50,6,14,4,0,15,'Frequency Information');
        GotoXY(3,3);
        Textcolor(2);
        Write('Lower edge frequency (GHz): ');
        Textcolor(10);
        Window(46,15,57,16);
        Readln(f1);
        Window(15,13,65,18);
        GotoXY(3,5);
        Textcolor(2);
        Write('Upper edge frequency (GHz): ');
        Textcolor(10);
        Window(46,17,55,18);
        Readln(f2);

        MAKE_WINDOW(15,16,50,6,14,4,0,15,'Modelling Specifications');
        GotoXY(3,3);
        Textcolor(2);
        Write('Ripple (dB): ');
        Textcolor(10);
        Window(30,18,57,19);
        Readln(Ripple);
        Window(15,16,65,22);
        GotoXY(3,5);
        Textcolor(2);
        Write('Number of elements: ');
        Textcolor(10);
        Window(37,20,55,21);
        Readln(nelements);

End;

Procedure g_CALCULATE;
var
        Beta,Gamma: REAL;
        a,b: ARRAY[0..50] of REAL;
        Zflag: INTEGER;
Begin
        Beta := Ln(Coth(Ripple/17.37));
```

```
Gamma := Sinh(Beta/(2*nelements));
g[0] := 1.0;
For k := 1 to nelements do
Begin
a[k] := Sin((2*k-1)*pi/(2*nelements));
b[k] := Sqr(Gamma)+Sqr(Sin(k*pi/nelements));
End;
g[1] := 2*a[1]/Gamma;
For k := 2 to nelements do
Begin
g[k] := (4*a[k-1]*a[k])/(b[k-1]*g[k-1]);
End;
If (nelements/2.0 <> nelements div 2) then
Begin
g[nelements+1] := 1.0
End;
If (nelements/2.0 = nelements div 2) then
Begin
g[nelements+1] := Sqr(Coth(Beta/4.0));
End;
MAKE_WINDOW(5,3,40,nelements+6,14,7,0,15,
'Tchebyscheff Element Values g(i)');
Textcolor(4);
For k := 0 to nelements+1 do
Begin
GotoXY(9,k+3);
Write('g',k,' = ');
End;
Textcolor(0);
For k := 0 to nelements+1 do
Begin
GotoXY(15,k+3);
Write(g[k]);
End;

Textcolor(31);
GotoXY(13,nelements+7);
Write(' Press Esc... ');
HOLDUNTIL(#27);
Textcolor(15);
GotoXY(13,nelements+7);
Write(' Press Esc... ');

End;
```

```
Procedure LOW_PASS_CALCULATE;
var
      Zflag: INTEGER;
Begin

      YA := 1.0/Zs;
      tbratio := t/b;
      omega1 := 2.0*pi*f1*1.0E+9;
      omegaQ := 2.0*pi*f2*1.0E+9;
      f0 := (f2+f1)/2.0;
      w := (f2-f1)/f0;
      theta0 := pi/2.0;
      Elem[0] := (Zs/g[0])*g[0];
      Elem[nelements+1] := (Zs/g[0])*g[nelements+1];
      Zflag := initelement;
      Z[0] := Elem[0];
      Z[nelements+1] := Elem[nelements+1];
      Units[0] := 'Ohms';
      Units[nelements+1] := 'Ohms';
      For k := 1 to nelements do
      Begin
            If (Zflag = 0) then
            Begin
                  Elem[k] := ((g[0]/Zs)*(1.0/omega1))*g[k];
                  Z[k] := Tan((pi/2.0)*(omega1/omegaQ))/(omega1*Elem[k]);
                  Zflag := 1;
                  Units[k] := 'Farads';
            End
            Else
            Begin
                  Elem[k] := ((Zs/g[0])*(1.0/omega1))*g[k];
                  Z[k] := (omega1*Elem[k])/Tan((pi/2.0)*(omega1/omegaQ));
                  Zflag := 0;
                  Units[k] := 'Henries';
            End;
      End;

      Lambda4 := (1000.0*c)/(4.0*Sqrt(epsilon)*f2*(1.0E+9)*2.54);  {mils}
End;


Procedure COMB_LINE_CALCULATE;
Begin
```

Appendix A

```
w := (f2-f1)/f0;
YA := 1.0/Zs;
tbratio := t/b;
omega1 := 2.0*pi*f1*1.0E+9;
omega2 := 2.0*pi*f2*1.0E+9;
f0 := (f2+f1)/2.0;
omega0 := 2.0*pi*f0*1.0E+9;
theta0 := (pi*theta0)/180.0;
```

{Normalized susceptance slope parameters}

```
bj := (Yaj/YA)*(Cot(theta0)+theta0*SQR(Csc(theta0)))/2.0;

GT[1] := w*bj/(g[0]*g[1]*omega1prime);

For j := 1 to nelements-1 do
Begin
      Jkk[j] := (w/omega1prime)*SQRT(bj*bj/(g[j]*g[j+1]));
End;

GT[nelements] := w*bj/(g[nelements]*g[nelements+1]*omega1prime);
```

{Normalized capacitances per unit length between each line and ground}

```
Ce[0] := (376.7*YA/SQRT(epsilon))*(1.0-SQRT(GT[1]));

Ce[1] := (376.7*YA/SQRT(epsilon))*(Yaj/YA - 1.0 + GT[1] - Jkk[1]*
Tan(theta0)) + Ce[0];

For j := 2 to nelements-1 do
Begin
     Ce[j] := (376.7*YA/SQRT(epsilon))*(Yaj/YA - Jkk[j-1]*
       Tan(theta0) - Jkk[j]*Tan(theta0));
End;

Ce[nelements+1] := (376.7*YA/SQRT(epsilon))*(1.0-SQRT(GT
  [nelements]));

Ce[nelements] := (376.7*YA/SQRT(epsilon))*(Yaj/YA - 1.0 +
  GT[nelements] - Jkk[nelements-1]*Tan(theta0)) + Ce[nelements+1];
```

```
{Normalized mutual capacitances per unit length between adjacent lines}

        CMe[0] := (376.7*YA/SQRT(epsilon))-Ce[0];

        For j := 1 to nelements-1 do
        Begin
            CMe[j] := (376.7*YA/SQRT(epsilon))*Jkk[j]*Tan(theta0);
        End;

        CMe[nelements] := (376.7*YA/SQRT(epsilon))-Ce[nelements+1];


{Lumped capacitances}

        For j := 1 to nelements do
        Begin
            Cs[j] := Yaj*(Cot(theta0)/omega0);
        End;

{Element line length (inches) }

        L := (1000.0*theta0*c)/(2.0*pi*SQRT(epsilon)*f0*1.0E9);   {mils}

    End;

    Procedure COMB_LINE_FOLLOW_UP;
    Begin
        Writeln;
        Writeln;
      Writeln('From table of curves (p. 188 "Microwave Filters..") Enter:');
        Writeln;
        Writeln;
        Writeln('Spacing to substrate thickness ratio');
        Writeln('-------------------------------------');
        Writeln;
        For i := 0 to nelements do
        Begin
            Write('(s/b) ',i,i+1,': ');
            Readln(spacing[i]);
            spacing[i] := 1000.0*spacing[i]*b;
        End;
```

```
Writeln;
Writeln;
Writeln('Fringing capacitances');
Writeln('————————————————————');
Writeln;
For i := 0 to nelements do
Begin
      Write('(Cfe/n) ',i,i+1,': ');
      Readln(Cfe[i]);
End;
Write('Isolated fringing capacitance (p. 190): ');
Readln(ICfe);

width[0] := (1000.0*b/2.0)*(1.0-t/b)*(Ce[0]/2.0-ICfe-Cfe[0]);
For i := 1 to nelements do
Begin
      width[i] := (1000.0*b/2.0)*(1.0-t/b)*(Ce[i]/2.0-Cfe[i-1]
      Cfe[i]);
End;
width[nelements+1] := (1000.0*b/2.0)*(1.0-t/b)*(Ce[nelements+1]
/2.0-ICfe-Cfe[nelements+1]);

Writeln(LST);
Writeln(LST,'Fringing capacitances');
Writeln(LST,'————————————————————');
Writeln(LST);
For i := 0 to nelements do
Begin
      Writeln(LST,i,'  ', Cfe[i]);
End;
Writeln(LST,'Isolated fringing capacitance: ',ICfe);
Writeln(LST);
Writeln(LST);
Writeln(LST,'Element widths (mils)');
Writeln(LST,'————————————————————');
Writeln(LST);
For i := 0 to nelements+1 do
Begin
      Writeln(LST,i,'  ',width[i]);
End;
Writeln(LST);
Writeln(LST);
Writeln(LST,'Element spacings (mils)');
```

```
        Writeln(LST,'————————————————————');
        Writeln(LST);
        For i := 0 to nelements do
        Begin
            Writeln(LST,i,',',i+1,'   ',spacing[i]);
        End;
        Writeln(LST,#12);
    End;


    Procedure WAVEGUIDE_CALCULATE;
    Begin


        YA := 1.0/Zs;
        omega1 := 2.0*pi*f1*1.0E+9;
        omega2 := 2.0*pi*f2*1.0E+9;
        f0 := (f2+f1)/2.0;
        omega0 := 2.0*pi*f0*1.0E+9;

{Plane wave wavelength at f0}
        lambda0 := c/(SQRT(epsilon)*f0*1.0E+9);

{Guide-wavelength fractional bandwidth}
        wL := (Lambdag(f1*1.0E+9,epsilon,a)-Lambdag(f2*1.0E+9,epsilon,a))
        /Lambdag(f0*1.0E+9,epsilon,a);

{Normalized impedance inverter parameters}
        KZ0[0] := SQRT((pi/2.0)*(wL/(g[0]*g[1]*omega1prime)));
        For i := 1 to nelements-1 do
        Begin
            KZ0[i] := (pi*wL/(2.0*omega1prime*SQRT(g[i]*g[i+1])));
        End;
        KZ0[nelements] := SQRT((pi/2.0)*(wL/(g[nelements]*g[nelements+1]
                          *omega1prime)));

{Shunt Reactances}
        For i := 0 to nelements do
        Begin
            XZ0[i] := KZ0[i]/(1.0 - SQR(KZ0[i]));
            XZ0La[i] := (XZ0[i]/a)*(Lambdag(f0*1.0E+9,epsilon,a));
        End;
```

Appendix A

```
{Element spacing electrical lengths}
        For i := 1 to nelements do
        Begin
            Theta[i] := pi-0.5*(ArcTan(2.0*XZ0[i-1])+ArcTan(2.0*XZ0[i]));
            spacing[i] := Theta[i]*Lambdag(f0*1.0E+9,epsilon,a)/(2.0*pi);
        End;


    End;


    Procedure LOW_PASS_SUMMARY;
    Begin
        MAKE_WINDOW(2,1,76,23,7,1,0,15,ID);
        Textcolor(3);
        GotoXY(5,2);
        Write('Date:');
        GotoXY(5,3);
        Write('System impedance (Ohms):');
        GotoXY(5,4);
        Write('Relative dielectric constant:');
        GotoXY(5,5);
        Write('Substrate thickness (inches):');
        GotoXY(5,6);
        Write('Conductor thickness (inches);');
        GotoXY(5,7);
        Write('Band edge frequency (GHz):');
        GotoXY(5,8);
        Write('Cutoff frequency (GHz):');
        GotoXY(5,9);
        Write('Ripple (dB):');
        GotoXY(5,10);
        Write('Number of elements:');
        GotoXY(5,11);
        Write('Line length (mils):');

        GotoXY(5,12);
        Write('i');
        GotoXY(5,13);
        Write('-');
        GotoXY(21,12);
        Write('g(i)');
        GotoXY(21,13);
```

```
Write('——');
GotoXY(38,12);
Write('Element values');
GotoXY(38,13);
Write('————————');
GotoXY(58,12);
Write('Impedances (Ohms)');
GotoXY(58,13);
Write('————————————');

Textcolor(11);
GotoXY(11,2);
Write(DATE);
GotoXY(35,3);
Write(Zs);
GotoXY(35,4);
Write(epsilon);
GotoXY(35,5);
Write(b);
GotoXY(35,6);
Write(t);
GotoXY(35,7);
Write(f1);
GotoXY(35,8);
Write(f2);
GotoXY(35,9);
Write(Ripple);
GotoXY(35,10);
Write(nelements);
GotoXY(35,11);
Write(Lambda4);

For i := 0 to nelements+1 do
Begin
      GotoXY(5,14+i):
      Write(i);
      GotoXY(14,14+i);
      Write(g[i]);
      GotoXY(36,14+i);
      Write(Elem[i]);
      GotoXY(58,14+i);
      Write(Z[i]);
End;
```

```
        Textcolor(31);
        GotoXY(32,24);
        Write(' Press Esc ');
        HOLDUNTIL(#27);
    End;


    Procedure LOW_PASS_PRINT_OUT;
    Begin
        Writeln(LST,'OUTPUT');
        Writeln(LST,'------');
        Writeln(LST);
        Writeln(LST,ID);
        Writeln(LST);
        Writeln(LST);
        Writeln(LST,'    Matching information');
        Writeln(LST,'    ----------------------');
        Writeln(LST);
        Writeln(LST,'System Impedance Zs: ',Zs);
        Writeln(LST);
        Writeln(LST);

        Writeln(LST,'    Substrate/Conductor information');
        Writeln(LST,'    ------------------------------------');
        Writeln(LST);
        Writeln(LST,'Relative dielectric constant: ',epsilon);
        Writeln(LST,'Substrate thickness (inches): ',b);
        Writeln(LST,'Conductor thickness (inches): ',t);
        Writeln(LST);
        Writeln(LST);

        Writeln(LST,'    Frequency information');
        Writeln(LST,'    ----------------------');
        Writeln(LST);
        Writeln(LST,'Band edge frequency (GHz): ',f1);
        Writeln(LST,'Cutoff frequency (GHz):   ',f2);
        Writeln(LST);
        Writeln(LST);

        Writeln(LST,'    Filter Modeling specifications');
        Writeln(LST,'    ------------------------------------');
        Writeln(LST);
        Writeln(LST,'Ripple (dB): ',ripple);
```

```
        Writeln(LST);
        Writeln(LST,'Number of elements: ',nelements);
        Writeln(LST);
        For i := 0 to nelements+1 do
        Begin
            Writeln(LST,'g(',i,'): ',g[i]);
        End;
        Writeln(LST);
        Writeln(LST,'    Lumped element values');
        Writeln(LST,'    ----------------------');
        Writeln(LST);
        For i := 0 to nelements+1 do
        Begin
            Writeln(LST,'Element(',i,'): ',Elem[i],'    ',Units[i]);
        End;
        Writeln(LST);
        Writeln(LST,'    Element impedances (Ohms)');
        Writeln(LST,'    --------------------------');
        Writeln(LST);
        For i := 0 to nelements+1 do
        Begin
            Writeln(LST,'Element(',i,'): ',Z[i]);
        End;
        Writeln(LST);
        Writeln(LST,'Transmission line length: ',Lambda4,'   mils');
        Writeln(LST,#12);

End;


Procedure BAND_PASS_PRINT_OUT;
Begin
        Writeln(LST,'OUTPUT');
        Writeln(LST,'------');
        Writeln(LST);
        Writeln(LST,ID);
        Writeln(LST);
        Writeln(LST);
        Writeln(LST,'    Matching information');
        Writeln(LST,'    --------------------');
        Writeln(LST);
        Writeln(LST,'System Impedance Zs: ',Zs);
        Writeln(LST);
```

```
Writeln(LST);

Writeln(LST,'    Substrate/Conductor information');
Writeln(LST,'    ------------------------------');
Writeln(LST);
Writeln(LST,'Relative dielectric constant: ',epsilon);
Writeln(LST,'Substrate thickness (inches): ',b);
Writeln(LST,'Conductor thickness (inches): ',t);
Writeln(LST,'t/b ratio: ',tbratio);
Writeln(LST);
Writeln(LST);

Writeln(LST,'    Frequency information');
Writeln(LST,'    ---------------------');
Writeln(LST);
Writeln(LST,'Center frequency (GHz): ',f0);
Writeln(LST,'Low-end frequency (GHz): ',f1);
Writeln(LST,'High-end frequency (GHz):   ',f2);
Writeln(LST,'Fractional bandwidth: ',w);
Writeln(LST);
Writeln(LST);

Writeln(LST,'    Filter Modeling specifications');
Writeln(LST,'    ------------------------------');
Writeln(LST);
Writeln(LST,'Ripple (dB): ',ripple);
Writeln(LST);
Writeln(LST,'Number of elements: ',nelements);
Writeln(LST);
For i := 0 to nelements+1 do
Begin
     Writeln(LST,'g(',i,'): ',g[i]);
End;
Writeln(LST);
Writeln(LST);

Writeln(LST,'    Miscellaneous parameters');
Writeln(LST,'    ------------------------');
Writeln(LST);

Writeln(LST,'Yaj/YA = ',Yaj/YA);
Writeln(LST,'bj/YA = ',bj);
Writeln(LST);
```

```
        Writeln(LST,'GT1/YA = ',GT[1]);
        For i := 1 to nelements-1 do
        Begin
            Writeln(LST,'J',i,i+1,'/YA = ',Jkk[i]);
        End;
        Writeln(LST,'GT',nelements,'/YA = ',GT[nelements]);
        Writeln(LST);
        Writeln(LST);

        Writeln(LST,'    Capacitance values');
        Writeln(LST,'    ——————————————');
        Writeln(LST);
        Writeln(LST,'Normalized cap./unit length between line & ground');
        Writeln(LST);
        For i := 0 to nelements+1 do
        Begin
            Writeln(LST,'C',i,'/n = ',Ce[i]);
        End;
        Writeln(LST);
        Writeln(LST,'Mutual capacitances');
        Writeln(LST);
        For i := 0 to nelements do
        Begin
            Writeln(LST,'C',i,i+1,'/n = ',CMe[i]);
        End;
        Writeln(LST);
        Writeln(LST,'Lumped capacitances');
        Writeln(LST);
        For i := 1 to nelements do
        Begin
            Writeln(LST,'Cs',i,' = ',Cs[i]);
        End;
        Writeln(LST);
        Writeln(LST);
        Writeln(LST,'Line length = ',L,' mils');
        Writeln(LST,#12);

End;


Procedure WAVEGUIDE_SUMMARY;
Begin
```

```
MAKE_WINDOW(2,1,76,23,7,1,0,15,ID);
Textcolor(3);
GotoXY(5,2);
Write('Date:');
GotoXY(5,3);
Write('System impedance (Ohms):');
GotoXY(5,4);
Write('Relative dielectric constant:');
GotoXY(5,5);
Write('Waveguide width(inches):');
GotoXY(5,6);
Write('Lower edge frequency (GHz):');
GotoXY(5,7);
Write('Upper edge frequency (GHz):');
GotoXY(5,8);
Write('Center frequency (GHz):');
GotoXY(5,9);
Write('Ripple (dB):');
GotoXY(5,10);
Write('Number of elements:');
GotoXY(5,11);
Write('a/lambda0:');

GotoXY(5,12);
Write('i');
GotoXY(5,13);
Write('-');
GotoXY(21,12);
Write('d(i)');
GotoXY(21,13);
Write('——');
GotoXY(38,12);
Write('Spacing (inches)');
GotoXY(38,13);
Write('————————————');
GotoXY(58,12);
Write('Reactances (Ohms)');
GotoXY(58,13);
Write('————————————');

Textcolor(11);
GotoXY(11,2);
Write(DATE);
```

```
GotoXY(35,3);
Write(Zs);
GotoXY(35,4);
Write(epsilon);
GotoXY(35,5);
Write(a);
GotoXY(35,6);
Write(f1);
GotoXY(35,7);
Write(f2);
GotoXY(35,8);
Write(f0);
GotoXY(35,9);
Write(Ripple);
GotoXY(35,10);
Write(nelements);
GotoXY(35,11);
Write(a/lambda0);

For i := 0 to nelements do
Begin
      GotoXY(5,14+i);
      Write(i);
      If dFLAG then
      Begin
            GotoXY(14,14+i);
            Write(d[i]);
      End;
      If (i >= 1) then
      Begin
            GotoXY(36,14+i);
            Write(spacing[i]);
      End;
      GotoXY(58,14+i);
      Write(XZ0La[i]);
End;


Textcolor(31);
GotoXY(32,24);
Write(' Press Esc ');
HOLDUNTIL(#27);
Textcolor(15);
```

```
        GotoXY(32,24);
        Write(' Press Esc ');
    End;

    Procedure WAVEGUIDE_DISTANCES;
    Begin
        dFLAG := TRUE;
        MAKE_WINDOW(3,2,40,nelements+5,7,1,0,15,'Element Distances');
        GotoXY(5,2);
        Write('From graph 8.06-2a on p. 453...');
        For i := 0 to nelements do
        Begin
            Textcolor(9);
            GotoXY(7,i+4);
            Write('d/a_',i,':');
            Textcolor(15);
            GotoXY(17,i+4);
            Read(da[i]);
            d[i] := da[i]*a;
        End;
        Textcolor(31);
        GotoXY(14,nelements+6);
        Write(' Press Esc ');
        HOLDUNTIL(#27);
        Textcolor(15);
        GotoXY(14,nelements+6);
        Write(' Press Esc ');
    End;


    Procedure WAVEGUIDE_PRINT_OUT;
    Begin
        Writeln(LST,'OUTPUT');
        Writeln(LST,'------');
        Writeln(LST);
        Writeln(LST,ID);
        Writeln(LST);
        Writeln(LST);
        Writeln(LST,'    Matching information');
        Writeln(LST,'    ------------------');
        Writeln(LST);
        Writeln(LST,'System Impedance Zs: ',Zs);
        Writeln(LST);
```

```
Writeln(LST);

Writeln(LST,'    Waveguide physical parameters');
Writeln(LST,'    ------------------------------');
Writeln(LST);
Writeln(LST,'Relative dielectric constant: ',epsilon);
Writeln(LST,'Width (inches): ',a);
Writeln(LST,'Width to plane-wave wavelength ratio: ',a/lambda0);
Writeln(LST);
Writeln(LST);

Writeln(LST,'    Frequency information');
Writeln(LST,'    ---------------------');
Writeln(LST);
Writeln(LST,'Center frequency (GHz): ',f0);
Writeln(LST,'Low-end frequency (GHz): ',f1);
Writeln(LST,'High-end frequency (GHz):   ',f2);
Writeln(LST,'Guide-wavelength fractional bandwidth: ',wL);
Writeln(LST);
Writeln(LST);

Writeln(LST,'    Wavelengths');
Writeln(LST,'    ----------');
Writeln(LST);
Writeln(LST,'Lambda_0 (inches): ',Lambda0);
Writeln(LST,'Lambdag_0 (inches): ',Lambdag(f0*1.0E+9,epsilon,a));
Writeln(LST,'Lambdag_1 (inches): ',Lambdag(f1*1.0E+9,epsilon,a));
Writeln(LST,'Lambdag_2 (inches): ',Lambdag(f2*1.0E+9,epsilon,a));
Writeln(LST);
Writeln(LST);

Writeln(LST,'    Filter Modeling specifications');
Writeln(LST,'    ------------------------------');
Writeln(LST);
Writeln(LST,'Ripple (dB): ',ripple);
Writeln(LST);
Writeln(LST,'Number of elements: ',nelements);
Writeln(LST);
For i := 0 to nelements+1 do
Begin
     Writeln(LST,'g(',i,'): ',g[i]);
End;
```

```
        Writeln(LST);
        Writeln(LST);

        Writeln(LST,'   Miscellaneous parameters');
        Writeln(LST,'   ------------------------');
        Writeln(LST);
        For i := 0 to nelements do
        Begin
            Writeln(LST,'K',i,i+1,'/Z0: ',KZ0[i]);
        End;
        Writeln(LST);
        For i := 0 to nelements do
        Begin
            Writeln(LST,'X',i,i+1,'/Z0: ',XZ0[i]);
        End;
        Writeln(LST);
        For i := 0 to nelements do
        Begin
            Writeln(LST,'(X',i,i+1,'/Z0)*(Lambdag0/a): ',XZ0La[i]);
        End;
        Writeln(LST);
        Writeln(LST);

        Writeln(LST,'   Element specifications');
        Writeln(LST,'   ---------- ------------');
        Writeln(LST);
        For i := 1 to nelements do
        Begin
            Writeln(LST,'Theta',i,' (radians): ',Theta[i]);
        End;
        Writeln(LST);
        For i := 1 to nelements do
        Begin
            Writeln(LST,'Spacing',i,'(inches): ',spacing[i]);
        End;
        Writeln(LST);
        For i := 0 to nelements do
        Begin
            Writeln(LST,'d',i,'(inches): ',d[i]);
        End;

        Writeln(LST,#12);

    End;
```

```
Procedure SELECT;
Begin
      If (Choice = 1) then
      Begin
            LOW_PASS_INPUT;
            g_CALCULATE;
            LOW_PASS_CALCULATE;
            LOW_PASS_SUMMARY;
      End;
      If (Choice = 2) then
      Begin
            BAND_PASS_INPUT;
            g_CALCULATE;
      End;
      If (Choice = 3) then
      Begin
            BAND_PASS_INPUT;
            g_CALCULATE;
            COMB_LINE_CALCULATE;
      End;
      If (Choice = 4) then
      Begin
            WAVEGUIDE_INPUT;
            g_CALCULATE;
            WAVEGUIDE_CALCULATE;
            WAVEGUIDE_SUMMARY;
            WAVEGUIDE_DISTANCES;
            WAVEGUIDE_SUMMARY;
      End;
End;


Procedure EXIT_OPTIONS;
var
   ChNum: CHAR;
   EChoice,errorcode: INTEGER;
Begin
      MAKE_WINDOW(15,9,50,10,14,4,8,15,'Options');
      Textcolor(3);
      GotoXY(10,4);
      Write('1. Data hardcopy');
      GotoXY(10,5);
      Write('2. Re-calculate same filter type');
```

```
GotoXY(10,6);
Write('3. Restart program');
GotoXY(10,7);
Write('4. Quit');
Textcolor(11);
GotoXY(10,4);
Write('1.');
GotoXY(10,5);
Write('2.');
GotoXY(10,6);
Write('3.');
GotoXY(10,7);
Write('4.');
Textcolor(31);
GotoXY(16,11);
Write(' Select number... ');

ChNum := #32;
While (ChNum<>'1') and (ChNum<>'2') and (ChNum<>'3') and
(ChNum<>'4') do
Begin
    ChNum := Readkey;
End;
Val(ChNum,EChoice,errorcode);

Textcolor(15);
GotoXY(16,11);
Write(' Select number... ');

If (EChoice = 1) then
Begin
    If (Choice = 1) then
    Begin
        LOW_PASS_PRINT_OUT;
    End;
    If (Choice = 2) then
    Begin
        BAND_PASS_PRINT_OUT;
    End;
    If (Choice = 3) then
    Begin
        BAND_PASS_PRINT_OUT;
    End;
```

```
            If (Choice = 4) then
            Begin
                WAVEGUIDE_PRINT_OUT;
            End;
        End;
        If (EChoice = 2) then
        Begin
            SELECT;
        End;
        If (EChoice = 3) then
        Begin
            MENU1;
        End;
        If (EChoice = 4) then
        Begin
            Halt;
        End;


    End;


BEGIN

    INTRO;
    MENU1;
    SELECT;
    EXIT_OPTIONS;
    END.
```

Appendix B. Touchstone Circuit Model of QUADLF (Excluding Waveguide Filter)

```
!
! Touchstone circuit model for Delay line limiter/filter.
! Project: Quasi-Active Delay Line Limiter/Filter.
! Project Engineer: Chance M. Glenn
! Date: 15Aug90
!
! Circuit filename: CMGDLF.CKT
!
!
DIM
        FREQ GHz
        LNG mil
        CAP pF
VAR
!  Substrate parameters
        epsilon     =     2.55      ! Relative dielectric constant
        Height      =     62.50     ! Substrate thickness
        Thick       =     1.00      ! Conductor thickness
        Resis       =     1.00      ! Relative resistivity of
                                    ! conductor
        RGH         =     8.00E-3   ! RMS surface roughness of conductor

!  Transmission line parameters
        Lambda4     =     1847.00   ! Quarter wavelength stub length
        Linput1     =     200.00    ! Length of input line
        Linput2     =     200.00    ! Length of input line
        Linput3     =     200.00    ! Length of input line
        W50         =     173.20    ! Line width for 50 ohms

!  PIN diode parameters
        DjCap       =     0.30      ! PIN diode junction capcitance
        DRs         =     1.00      ! PIN diode series resistance
        DLs         =     0.90      ! PIN diode series inductance
        DCp         =     0.18      ! PIN diode package capacitance

!  Waveguide delay-line parameters
        WGeps       =     78.99     ! Waveguide dielectric constant
        Lwvgd1      =     6000.00   ! Limiter positioning in waveguide
        WGwth       =     1020.00   ! Waveguide width
        WGht        =     551.00    ! Waveguide height
```

Appendix B

```
!  Miscellaneous parameters
        Cf          =        2.70      ! Filtering capacitor
        Cc          =        0.30      ! Coupling capacitor
        CNotch      =      160.00      ! Notching circuit capacitance
        Rlim        =     8000.00      ! Limiter diode resistance
        Wf          =       27.10      ! Width of filter line
        Lbias       =     1000.00      ! Length of DC bias line
        Lf          =      500.00      ! Length of filter line
        Rbias1      =     8000.00      ! Value of biasing resistor (Shunt)
        Rbias2      =        1.00      ! Value of biasing resistor
        Wbias       =       20.00      ! Width of DC bias line
        WNotch      =       50.00      ! Width of notching line
        LNotch      =     2000.00      ! Length of notching line
        Lout1       =      500.00      ! Length of output line

CKT

! Micro-Strip substrate
        MSUB      er^epsilon  h^Height  T^Thick Rho^Resis rgh^RGH

! Input line
        MLIN 1 2 w^W50 L^Linput

! DC Biasing circuit
        CAP  2 3 C^Cc
        RES  3 0 R^Rbias1
        RES  3 4 R^Rbias2
        MLIN 4 5 W^Wbias L^Lbias

! Low Pass Filter
        MLIN 2 6 W^W50 L^Linput2
        CAP  6 0 C^Cf
        MLIN 6 7 W^Wf L^Lf
        CAP  7 0 C^Cf
        MLIN 7 8 W^W50 L^Linput3

! Delay/Waveguide Section
        RWG  8 9    a^WGwth b^WGht L^Lwvgd er^WGeps Rho^Resis

! Two Diode Limiter Section
        PIN2  9  0 CJ^DjCap RJ^Rlim RS^DRs LS^DLs CP^DCp
        MLIN  9 10 W^W50 L^Lmbda4
        PIN2 10  0 CJ^DjCap RJ^Rlim RS^DRs LS^DLs CP^DCp
```

```
        MLIN 10  5 W^WNotch L^LNotch
        CAP   5  0 C^CNotch
        MLIN 10 11 W^W50 L^Lout1

! Output definition
        DEF3P 1 4  11   CMGDLF
FREQ
        SWEEP 0.10 10.0 0.099
OUT
        CMGDLF dB[S31] GR1
        CMGDLF dB[S21] GR1
GRID
        RANGE 0.20 10.0 0.99
        GR1  0 -70 5
```

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